Electron scattering for neutrino physics at MAMI and MESA

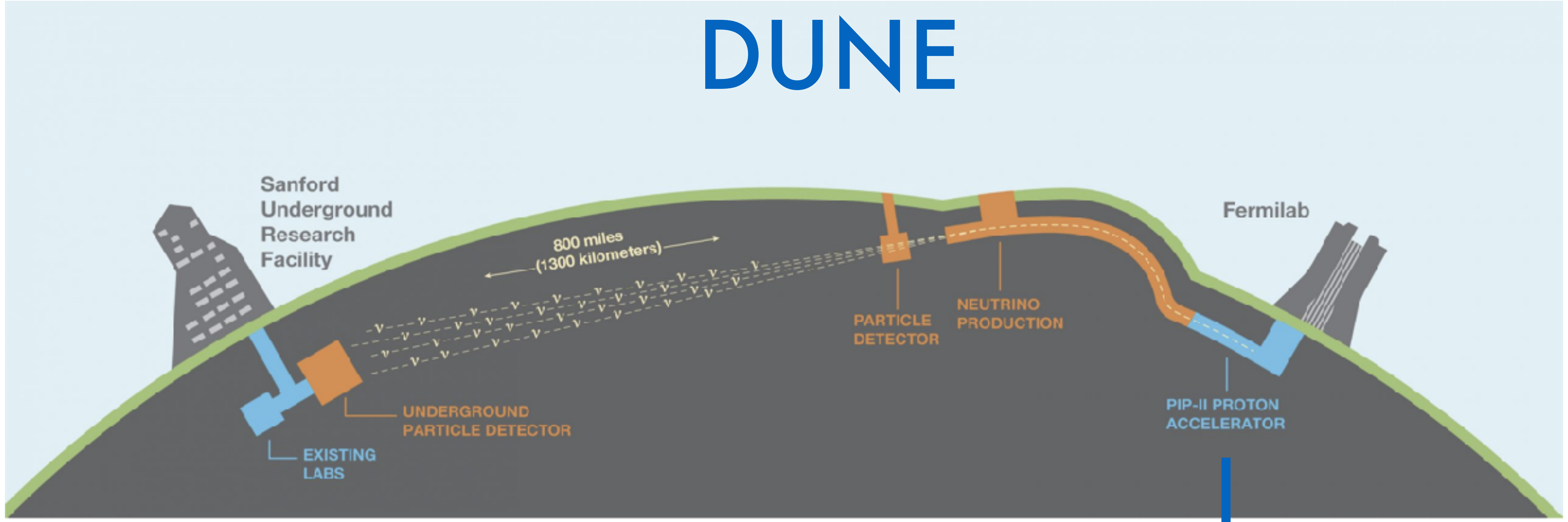
Luca Doria (doria@uni-mainz.de)
PRISMA+ Cluster of Excellence and Institute for Nuclear Physics
Johannes Gutenberg University Mainz

Neutrino Cross Section Topical Group (NF06)
Low Energy Neutrino and Electron Scattering Workshop

Introduction

- Experiments at MAMI (up to 1600 MeV)
  - Present
  - Future opportunities
- Future Directions: MESA (up to ~100 MeV)

Long Base-Line Experiments



Near Detector

$$N_{ND}(\nu_\alpha, E_R) = \int dE_\nu \Phi_{\nu_\alpha}(E_\nu) \times \sigma(E_\nu) \times R_{\nu_\alpha}(E_\nu, E_R)$$

Far Detector

$$N_{FD}(\nu_\alpha \to \nu_\beta, E_R) = \int dE_\nu \Phi_{\nu_\alpha}(E_\nu) \times \sigma(E_\nu) \times R_{\nu_\alpha}(E_\nu, E_R) \times P(\nu_\alpha \to \nu_\beta, E_\nu)$$

Why electrons are relevant for neutrino physics ?

Neutrino-Nucleus scattering

$$\frac{d^2\sigma}{d\Omega_{k'}d\omega} = \sigma_0 \left[L_{CC}R_{CC} + L_{CL}R_{CL} + L_{LL}R_{LL} + L_T R_T \pm L_{T'}R_{T'}\right]$$

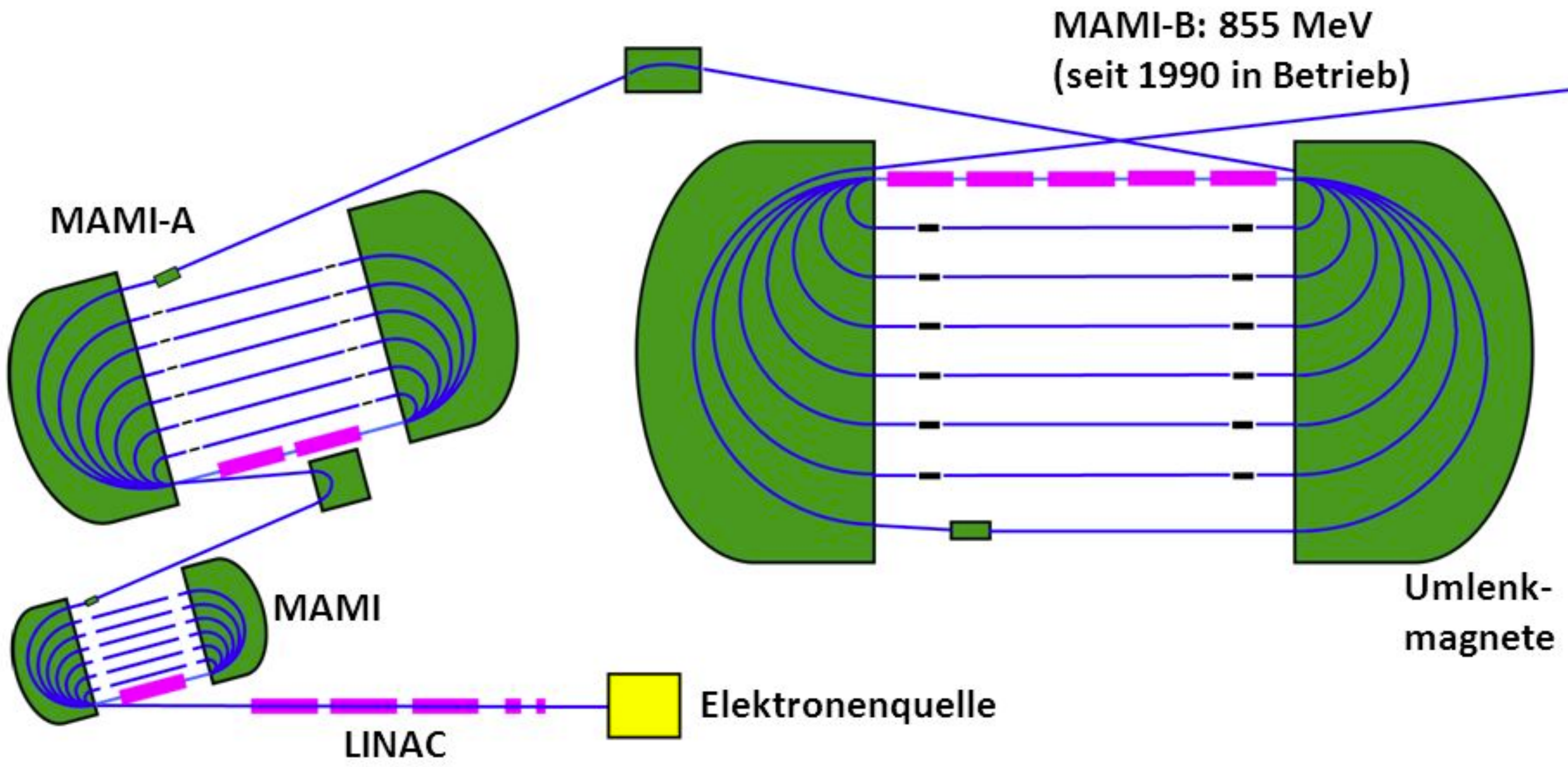
(Unpolarized) Electron-Nucleus scattering

$$\frac{d^2\sigma}{d\Omega d\omega} = \left(\frac{d\sigma}{d\Omega}\right)_{Mott}\left[\frac{Q^4}{\vec{q}^4}R_L(q) + \left(\frac{1}{2}\frac{Q^2}{\vec{q}^2} + \tan^2\frac{\theta}{2}\right)R_T(q)\right] = \left(\frac{d\sigma}{d\Omega}\right)_{Mott}\left[\sigma_L + \sigma_T\right]$$

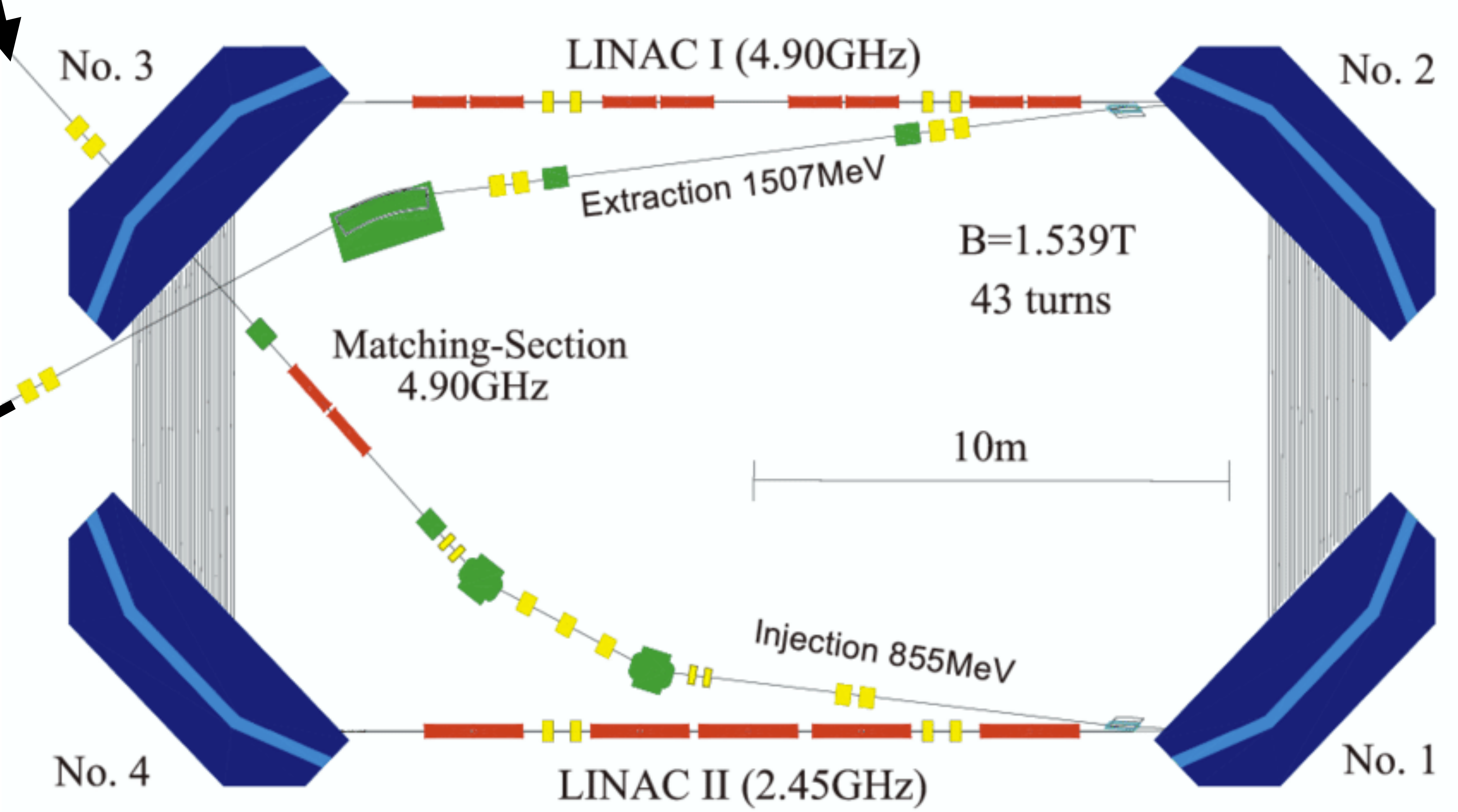
Use electrons for testing neutrino-nucleus interactions generators.

The MAMI Facility

The Racetrack Microton (Institute for Nuclear Physics, U. Mainz)



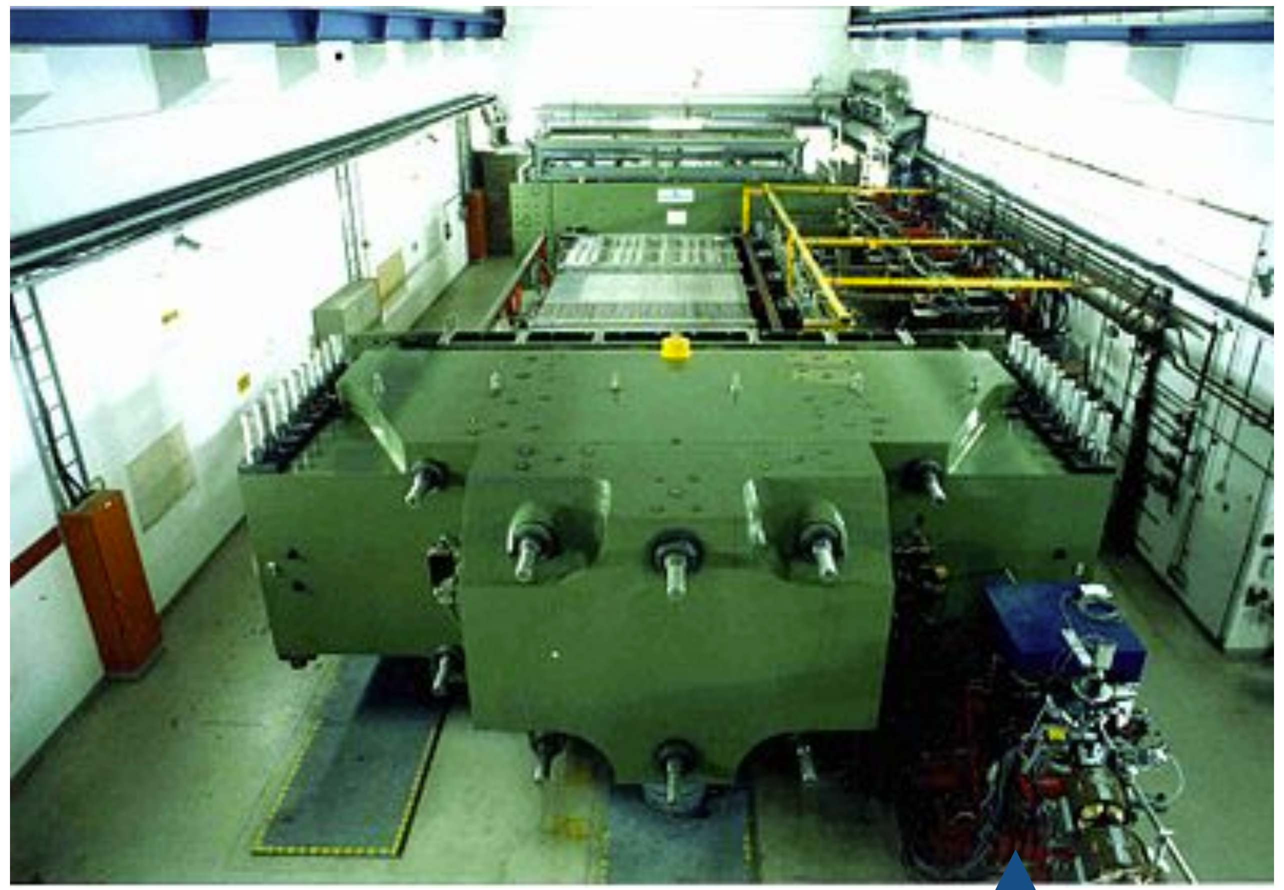
up to 855 MeV

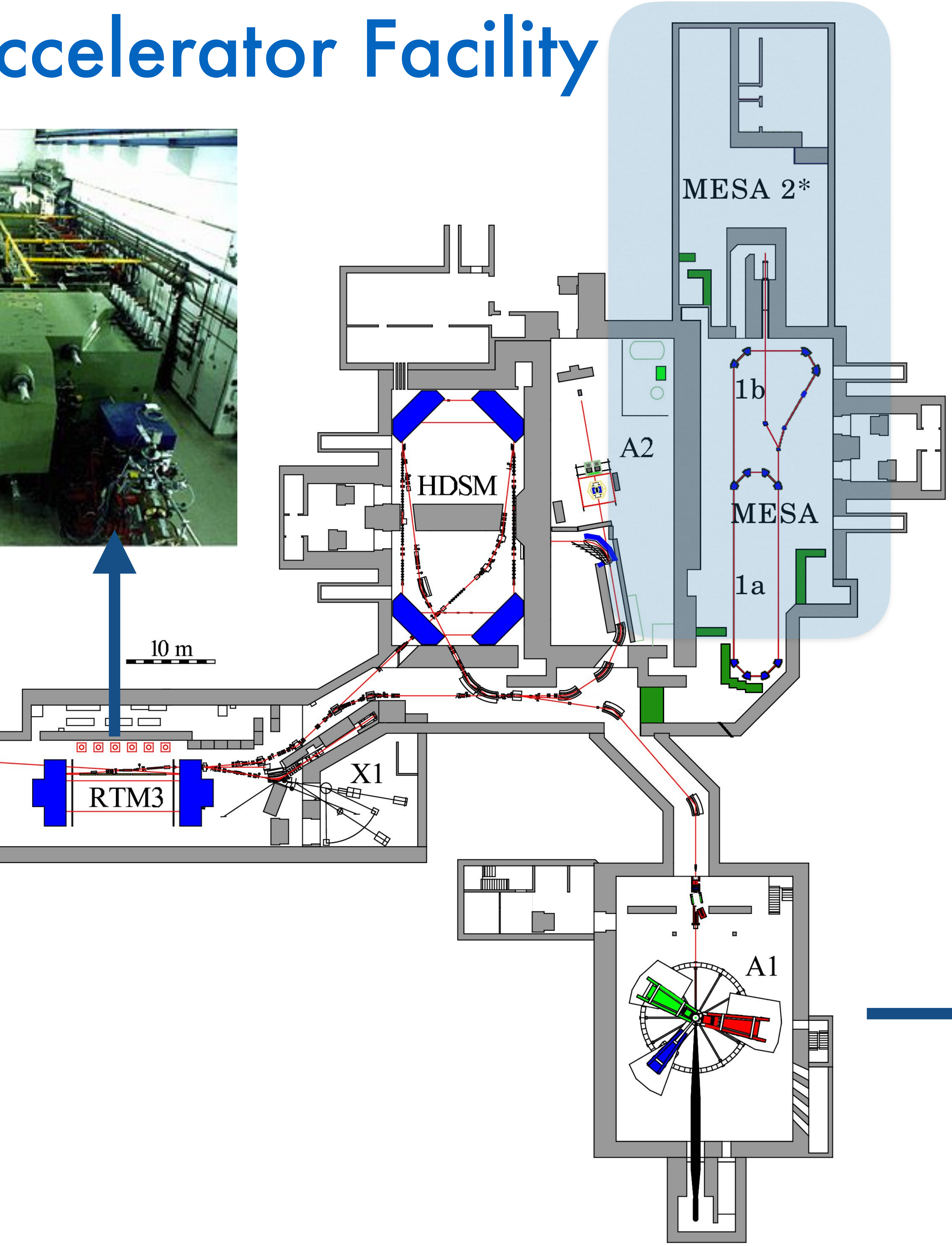


CW electron beam
Up to 100 uA current
80% polarization
dE <13 keV

up to 1.6 GeV

The MAMI Accelerator Facility

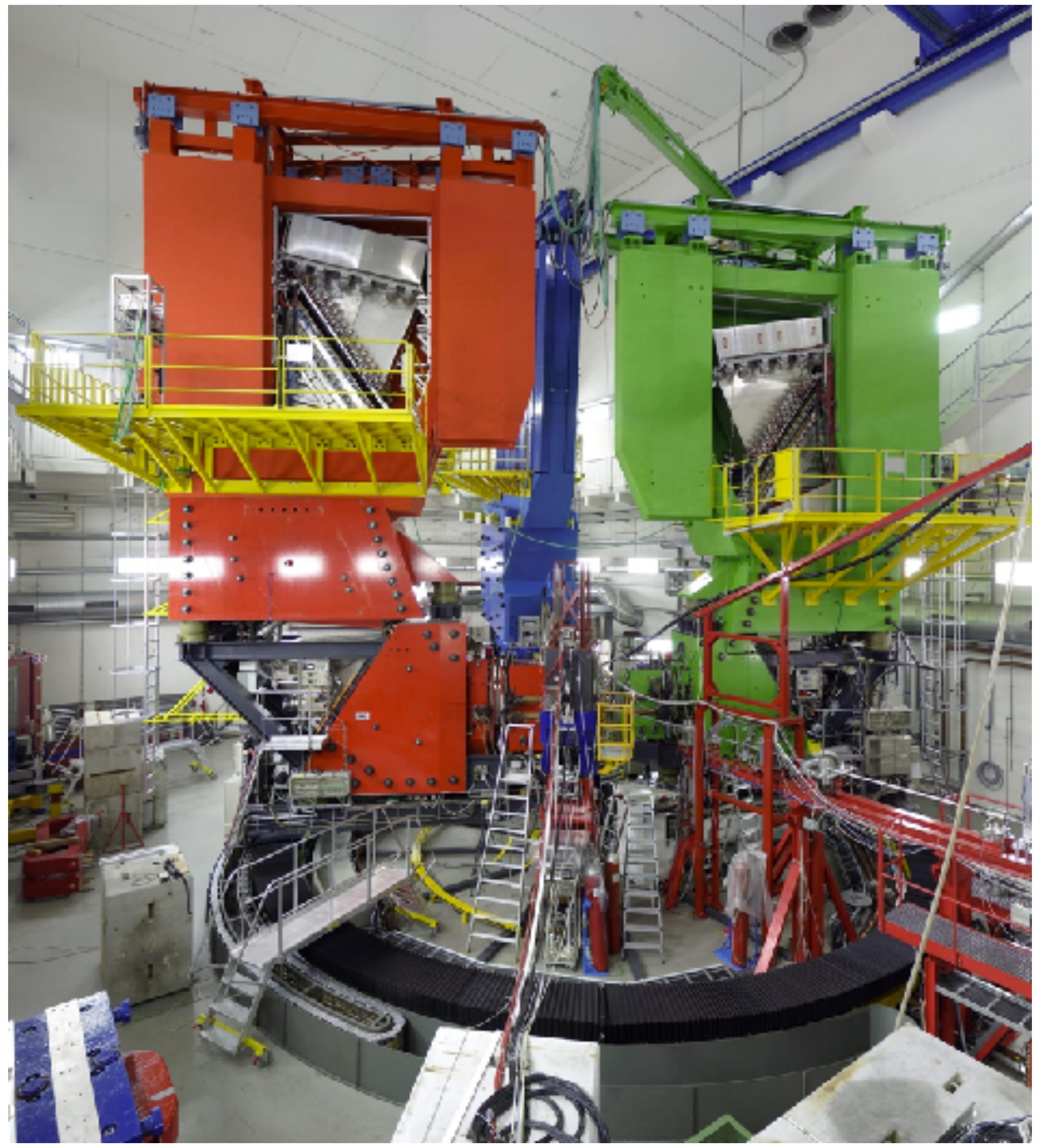




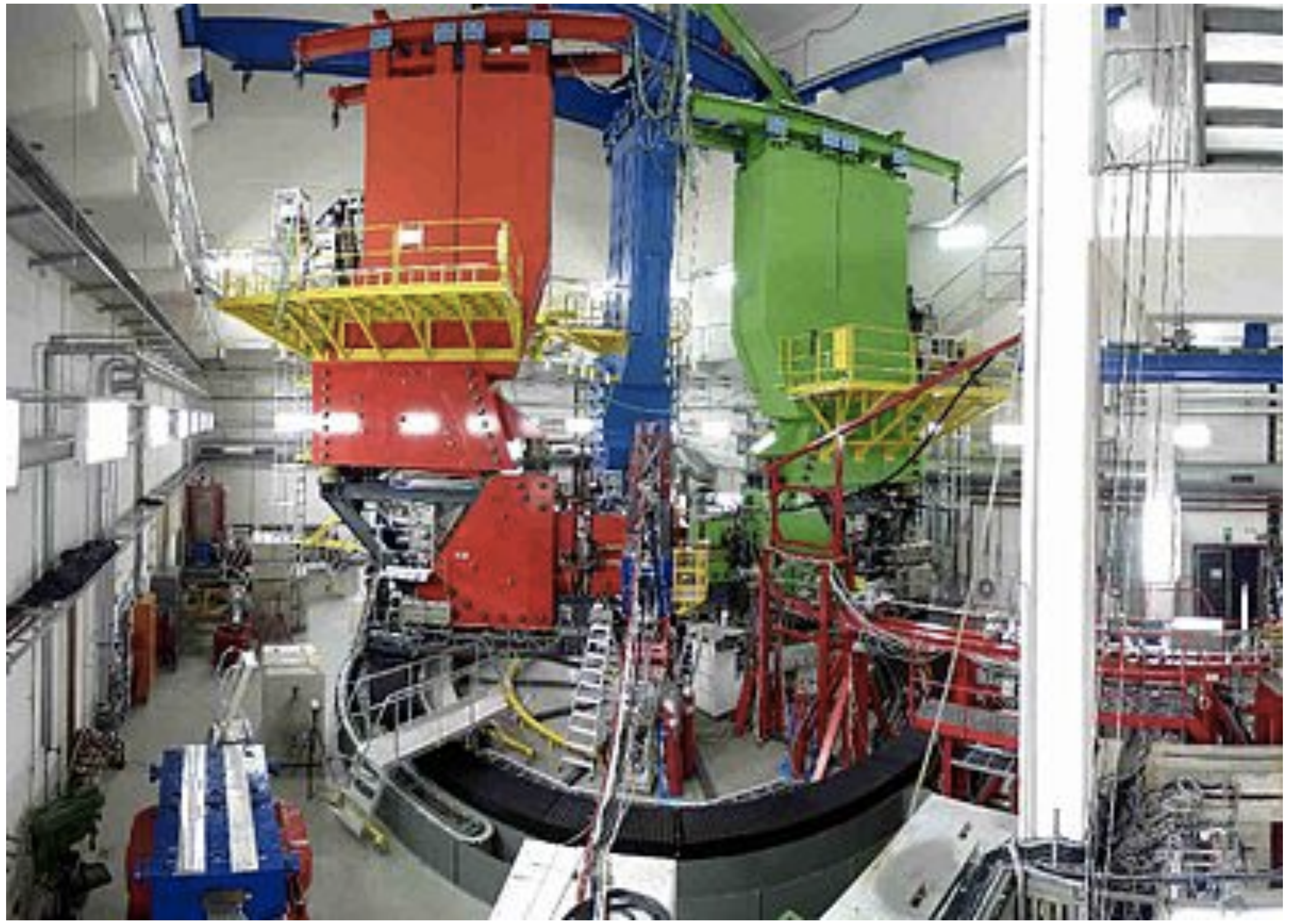
MESA

Mainz
Energy-recovery
Superconducting
Accelerator

A1 Collaboration
3-Spectrometers Setup

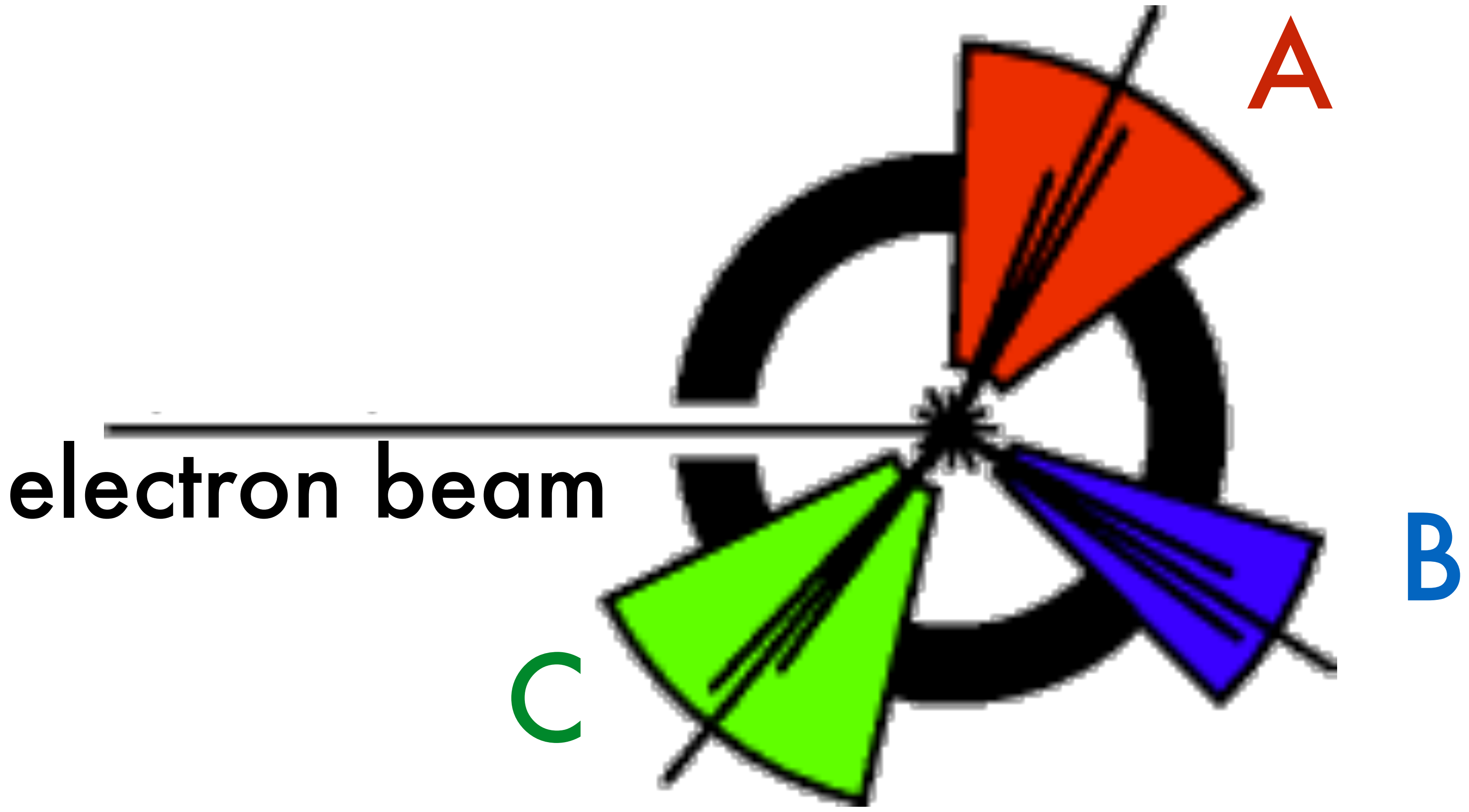


A1 Collaboration



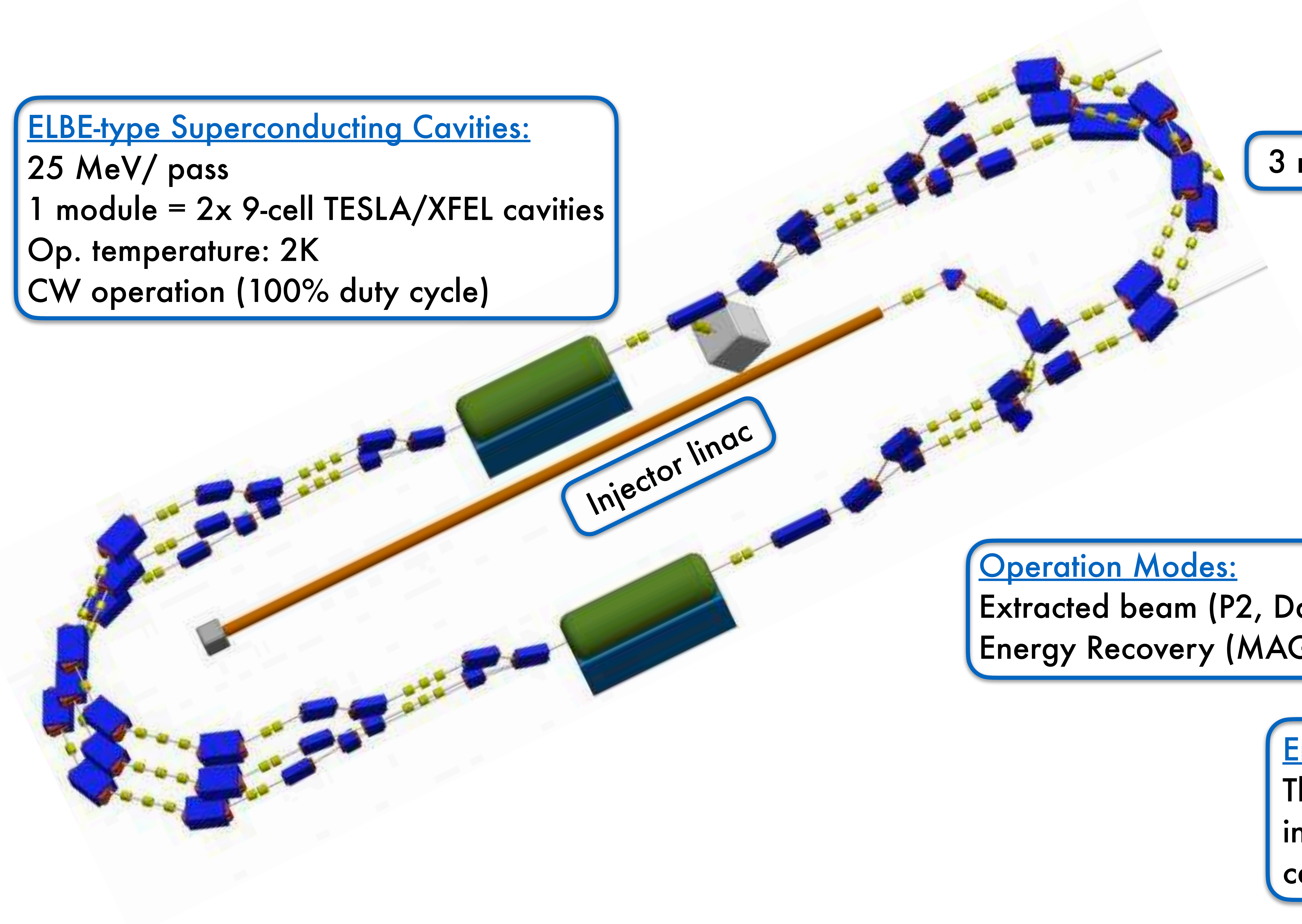
Spectrometers

	A	B	C
Configuration	QSDD	D	QSDD
Max.Momentum (MeV)	735	870	551
Solid Angle (msr)	28	5,6	28
Mom. Resolution	10^{-4}	10^{-4}	10^{-4}
Pos. Res at Target (mm)	3-5	1	3-5



The MESA Facility

MESA: Mainz Energy-Recovery Superconducting Accelerator

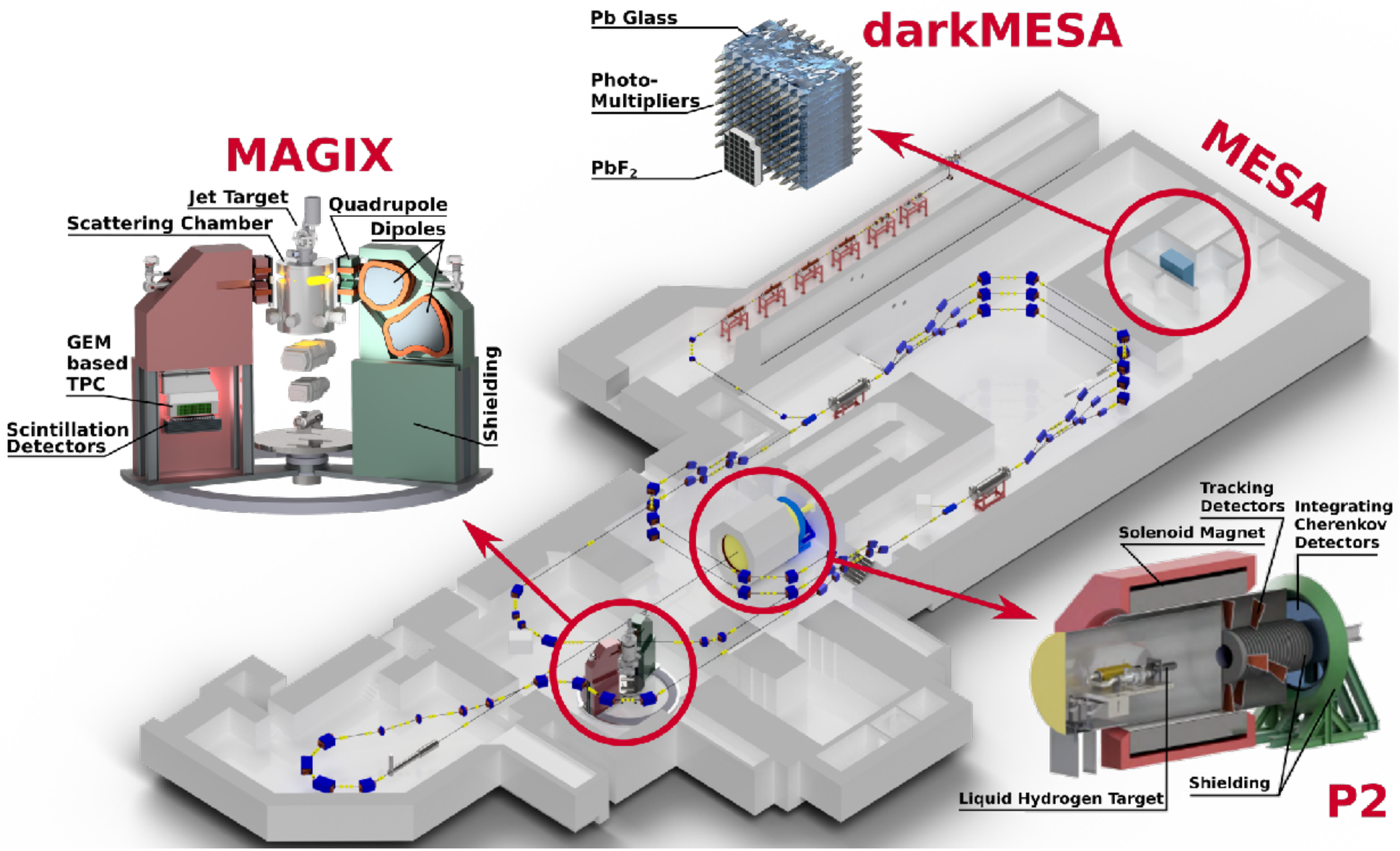


ELBE-type Superconducting Cavities:
25 MeV/ pass
1 module = 2x 9-cell TESLA/XFEL cavities
Op. temperature: 2K
CW operation (100% duty cycle)

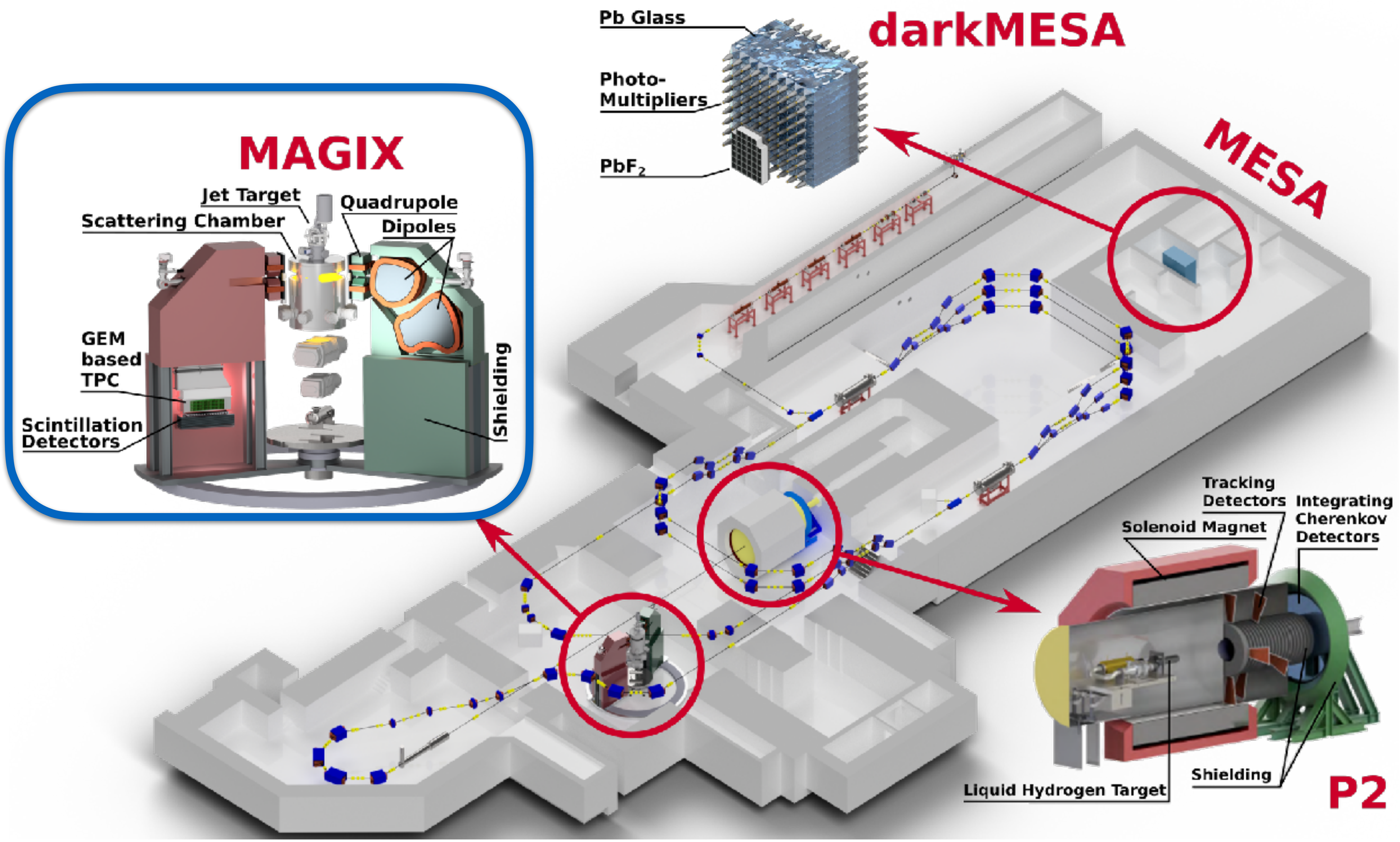
Operation Modes:
Extracted beam (P2, DarkMESA): E_{beam} = 155 MeV, I_{beam} = 150uA
Energy Recovery (MAGIX): E_{beam} = 105 MeV, I_{beam} = 1mA

Energy Recovery mode:
The beam is reinserted after 3 recalculations in couterphase: the energy goes back to the cavities and the beam is dumped at 5 MeV.

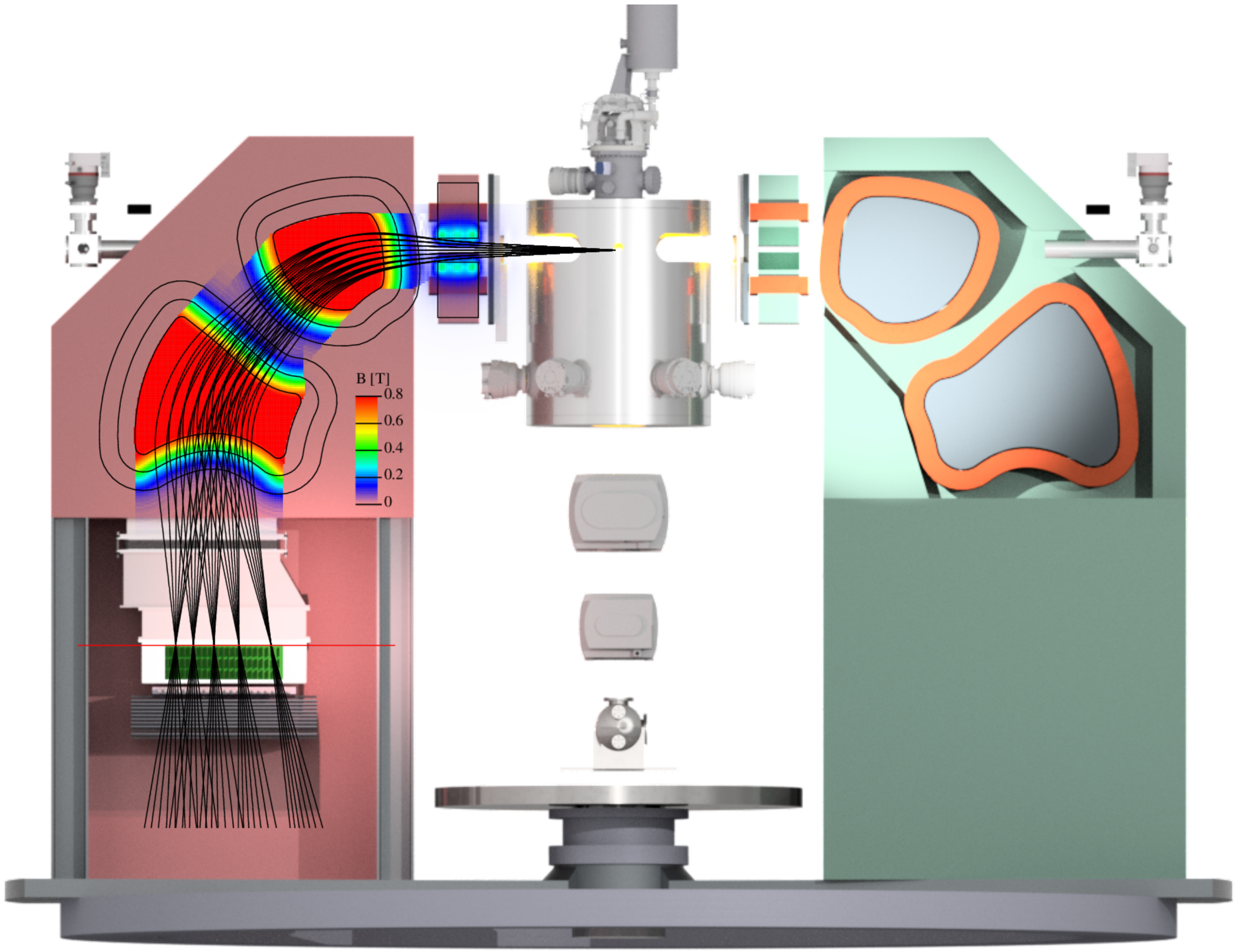
The MAGIX experiment



The MAGIX experiment



The MAGIX experiment



Rotation: 15°-165°

Detectors:

- Low-mass GEM-based TPC.
- Plastic Scintillators for triggering and veto.

Timing

- TPC trigger: ~1 ns
- coincidence time STAR↔PORT: ~100 ps

Focal Plane resolutions (*p*-dependent etc)

- positions: ~100 μm angles: ~3.5 mrad

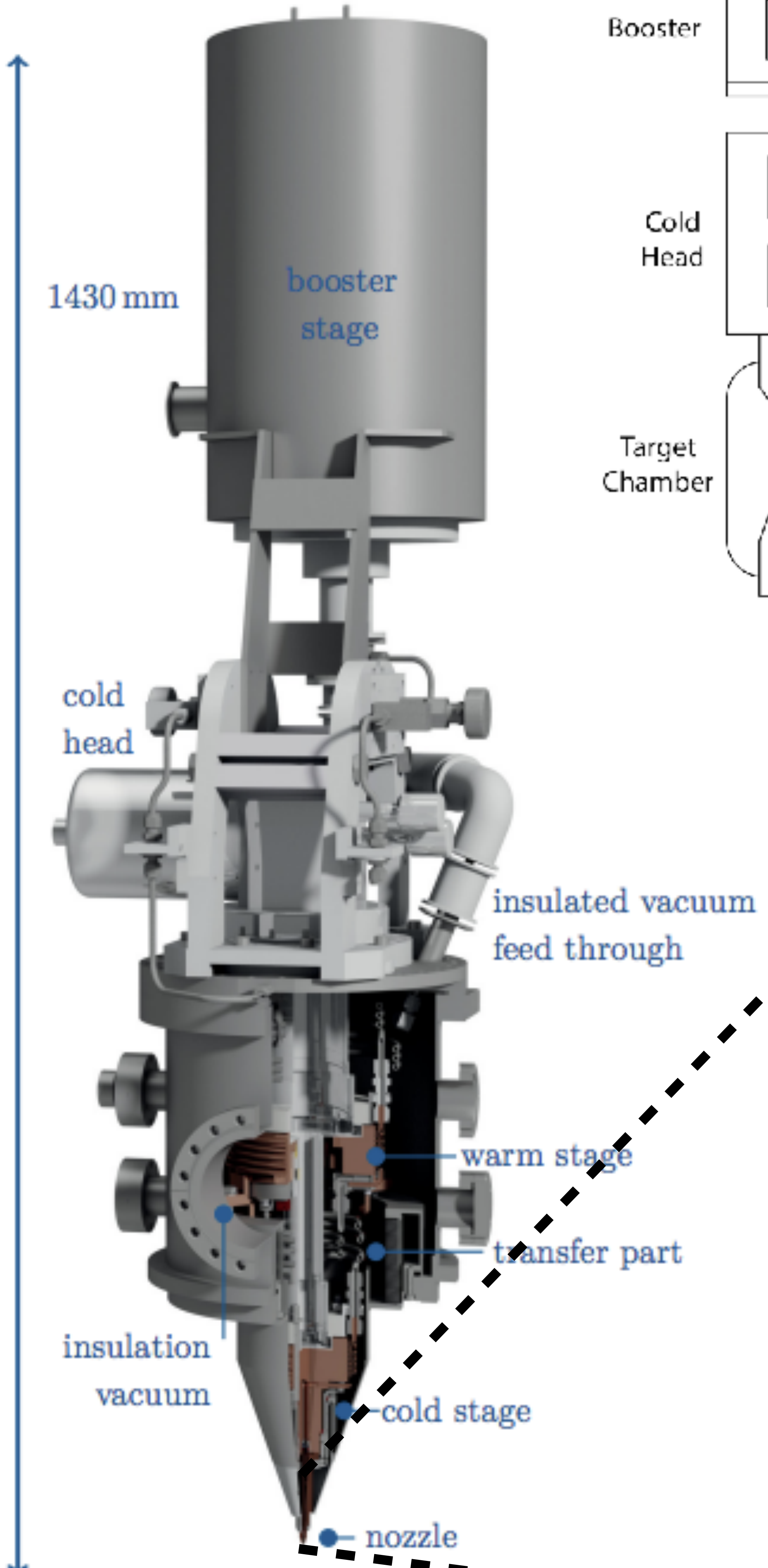
Expected Resolution

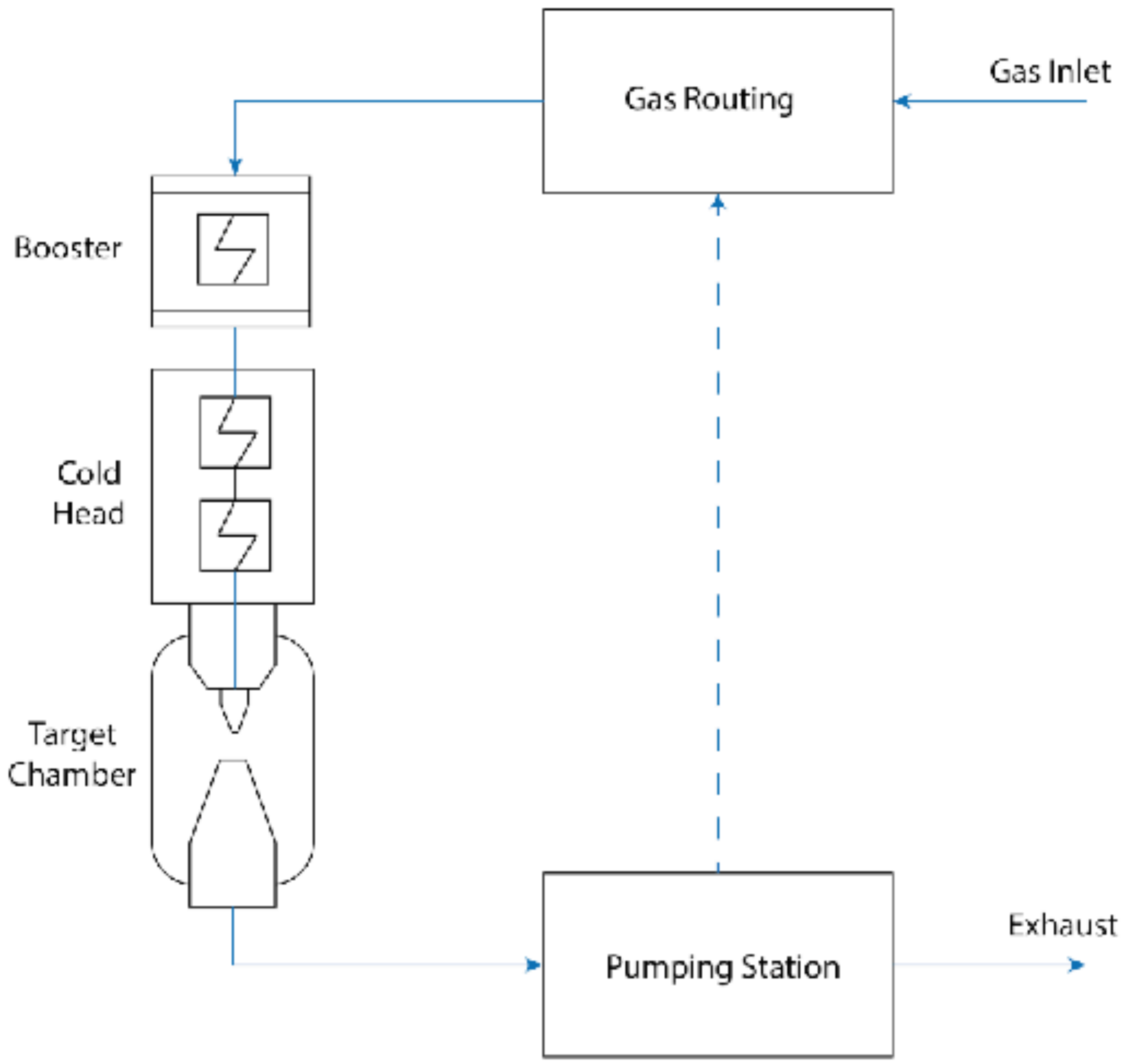
- dp/p: 6×10^{-5}
- in-plane angle ϕ_0: 6.5 mrad
- oop angle θ_0: 1.6 mrad vertex y_0: 60 μm

Acceptances

- momentum acceptance: ± 15 %
- solid angle: 18 msr

Jet Target

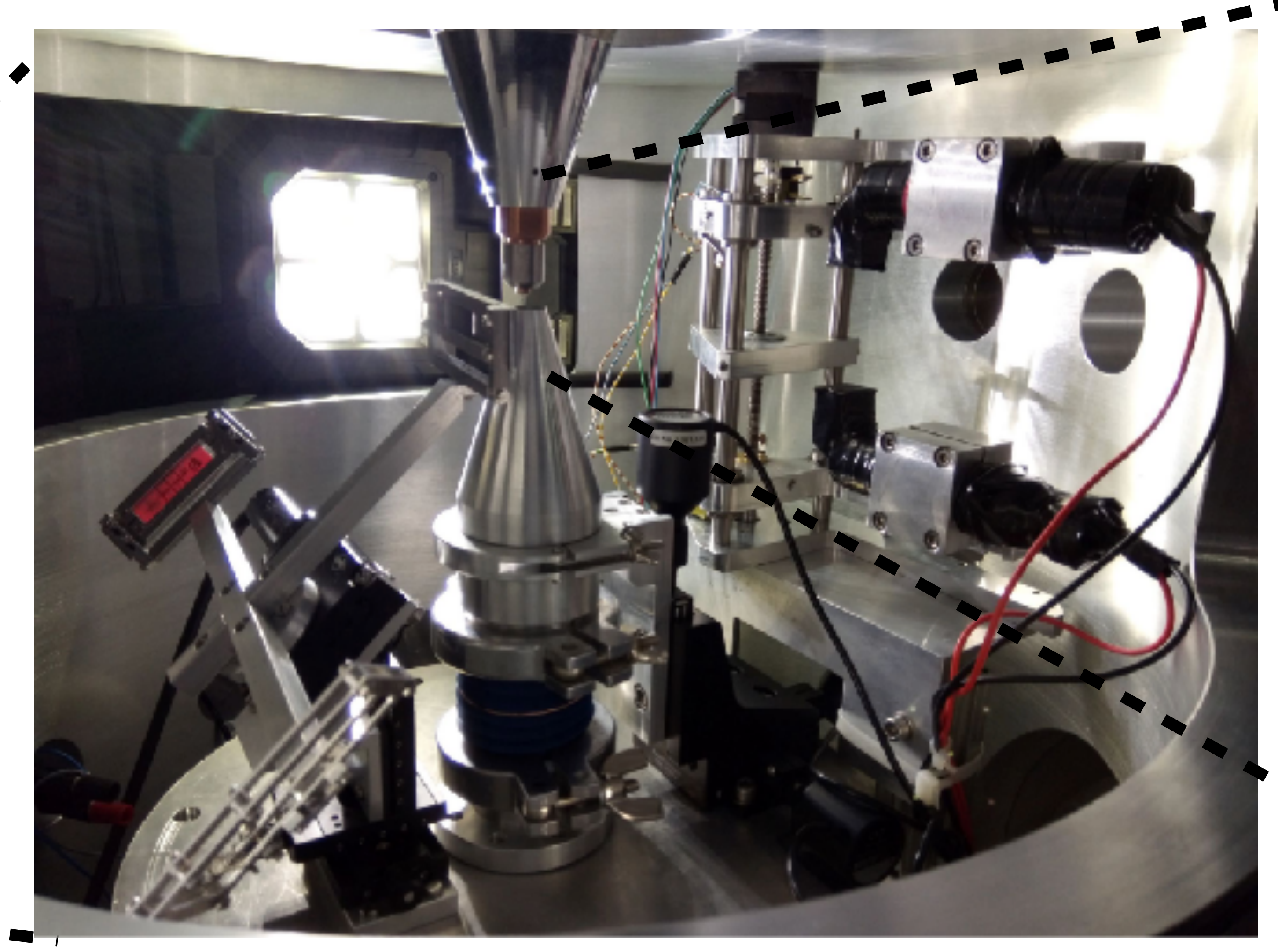


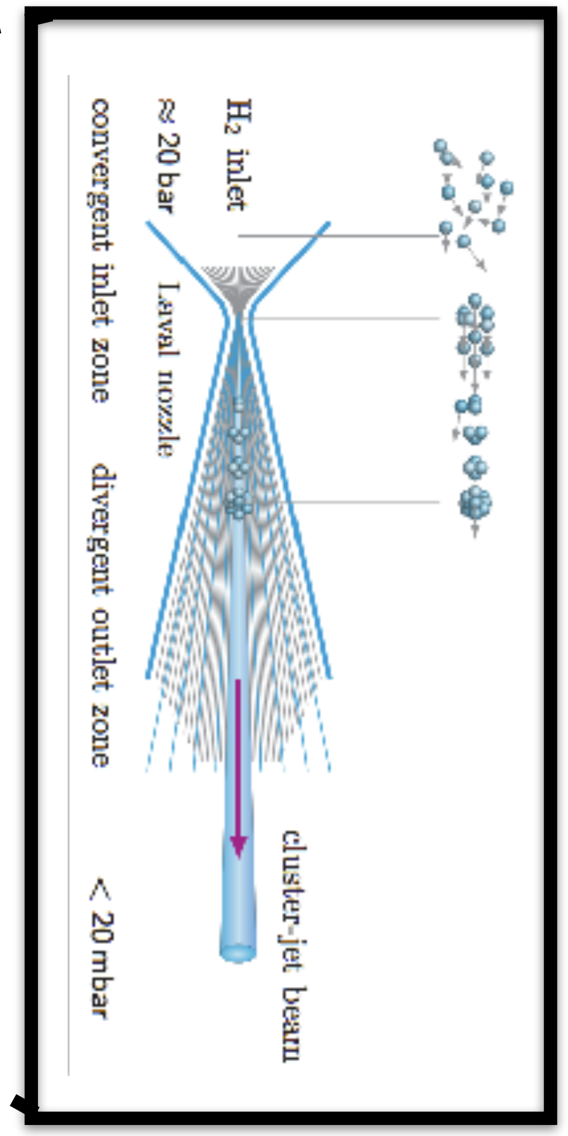


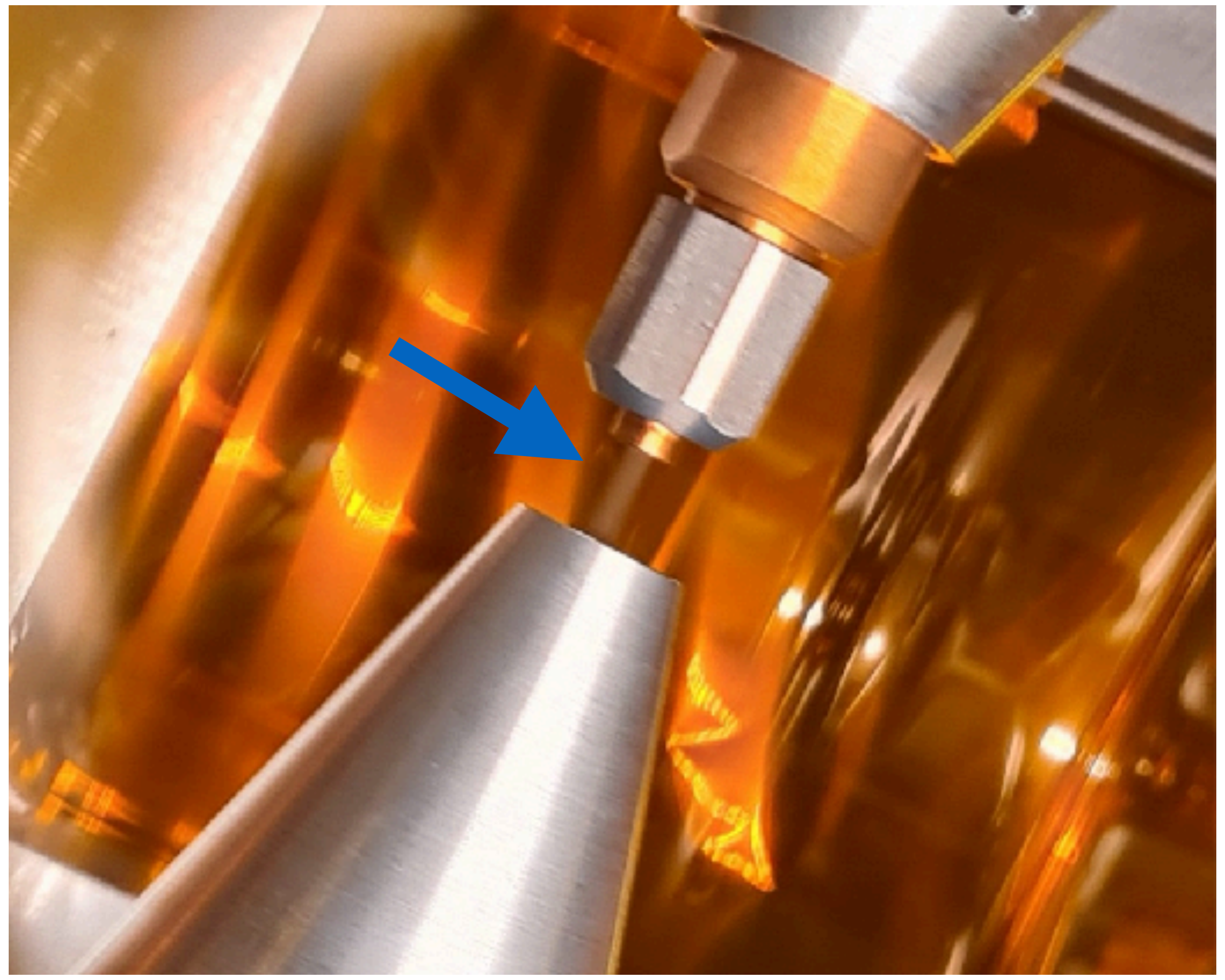
- Supersonic gas flow from Laval nozzle
- Supersonic shockwaves and clustering at cryogenic temperatures limit gas diffusion
- mm-wide collimated gas stream
- Well tested with hydrogen (“proton target”)
- Successfully operated with <u>argon</u> for the first time: milestone for MAGIX

B.S. Schlimme *et al.,* Nucl. Instr. Meth. Phys. Res. A 1013, 165668 (2021)

S. Grieser *et al.,* Nucl. Instr. Meth. A 906, 120-126 (2018)

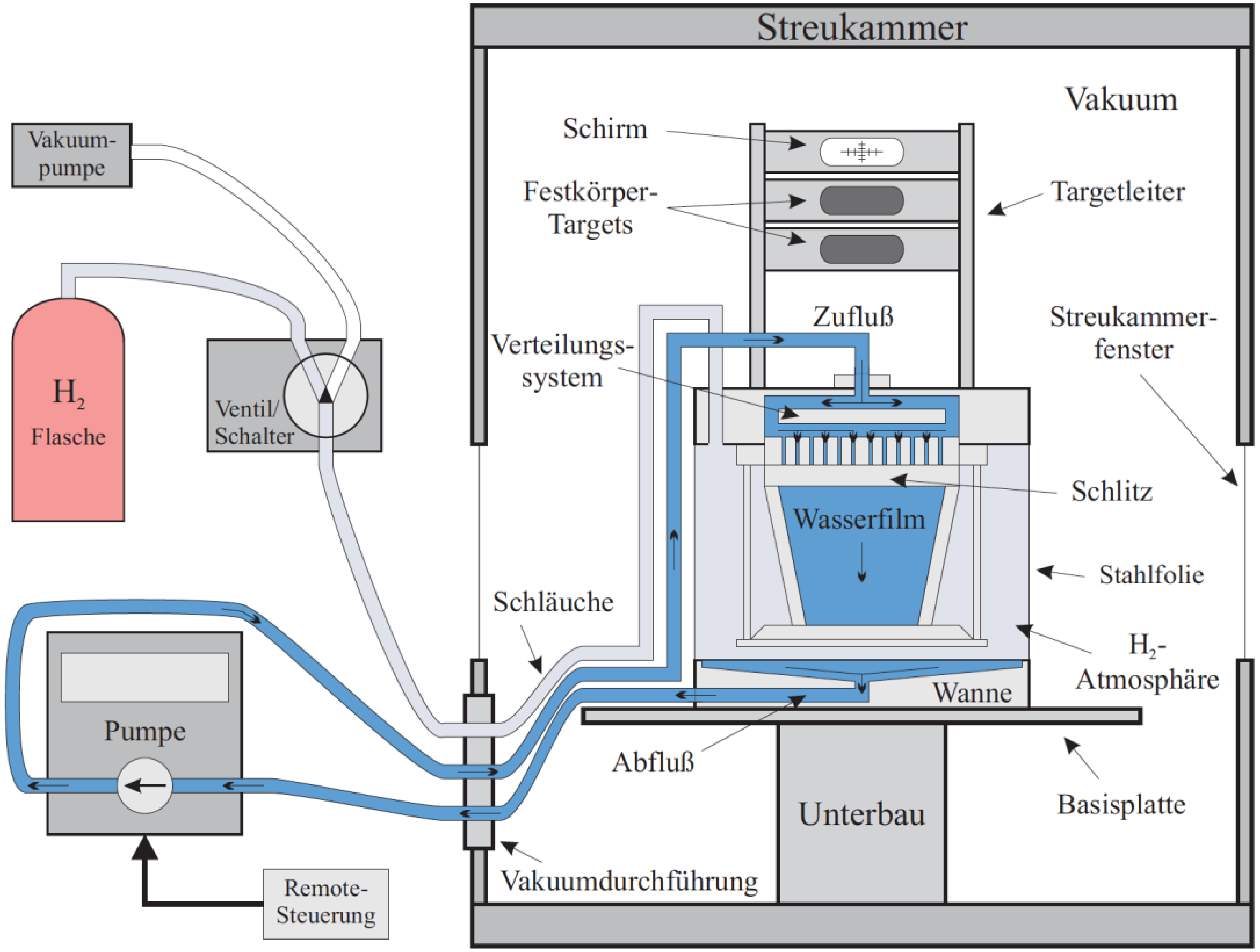






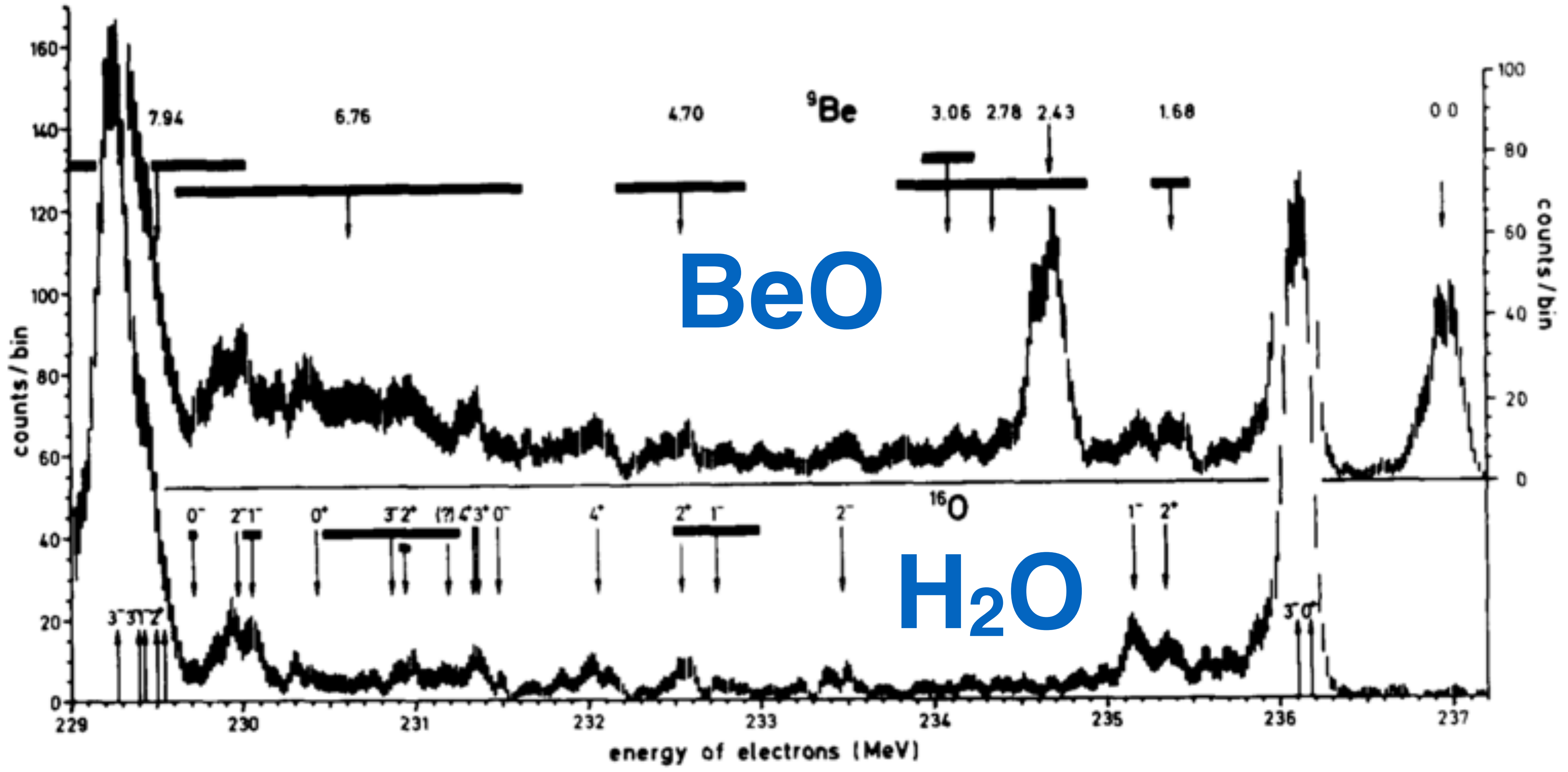
(Near?) future: Oxygen

Waterfall target



- Density = 28 mg/cm²
- Laser-monitored
- Other option: high-pressure target

N. Voegel, J. Friedrich, Nucl. Instr. Meth. 198, 293 (1982)



Data Taking Campaigns: Present and Future

Electron Scattering Dataset

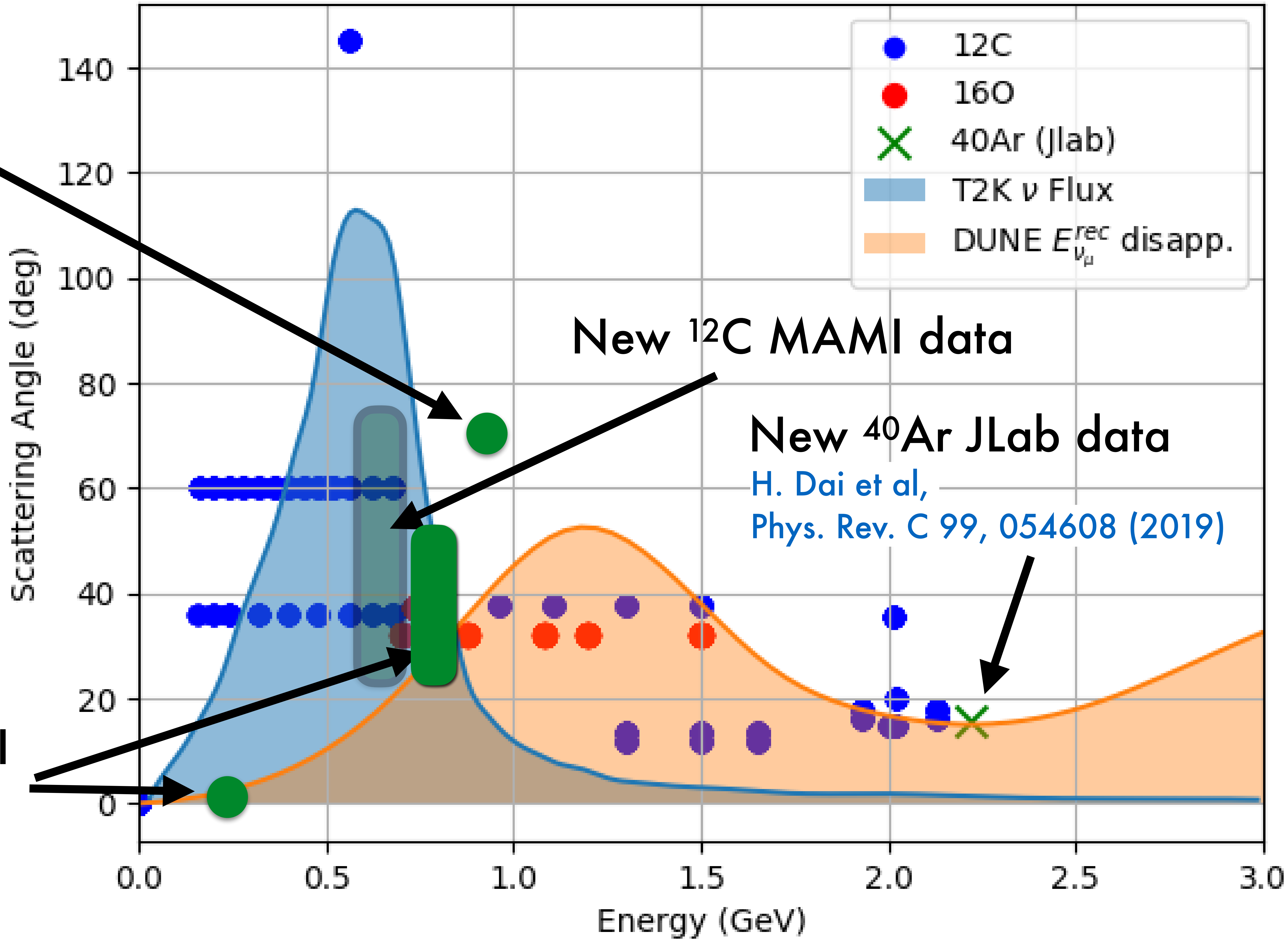
New ^{12}C MAMI (analysis finalised)

New ^{12}C MAMI data

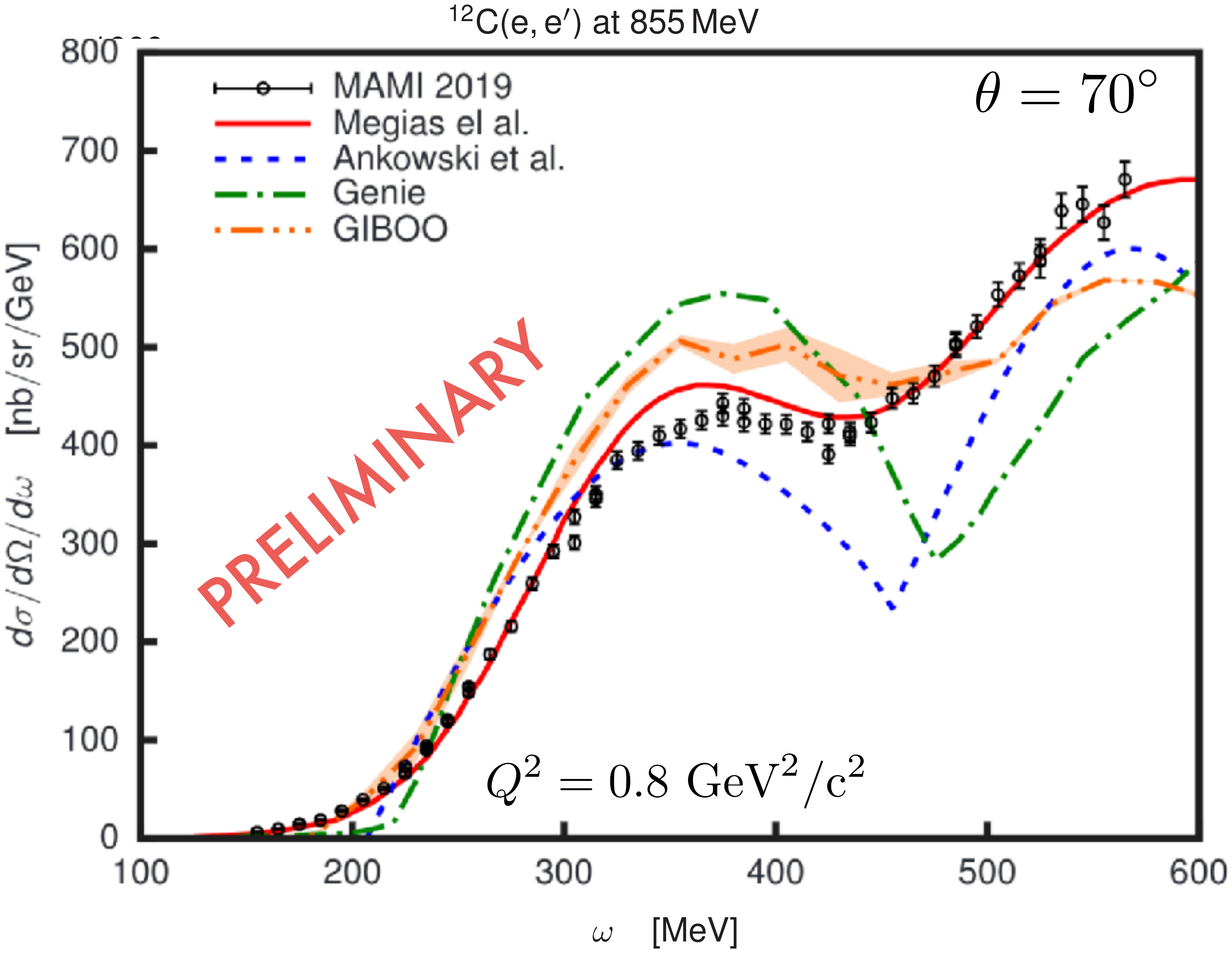
New ^{40}Ar JLab data

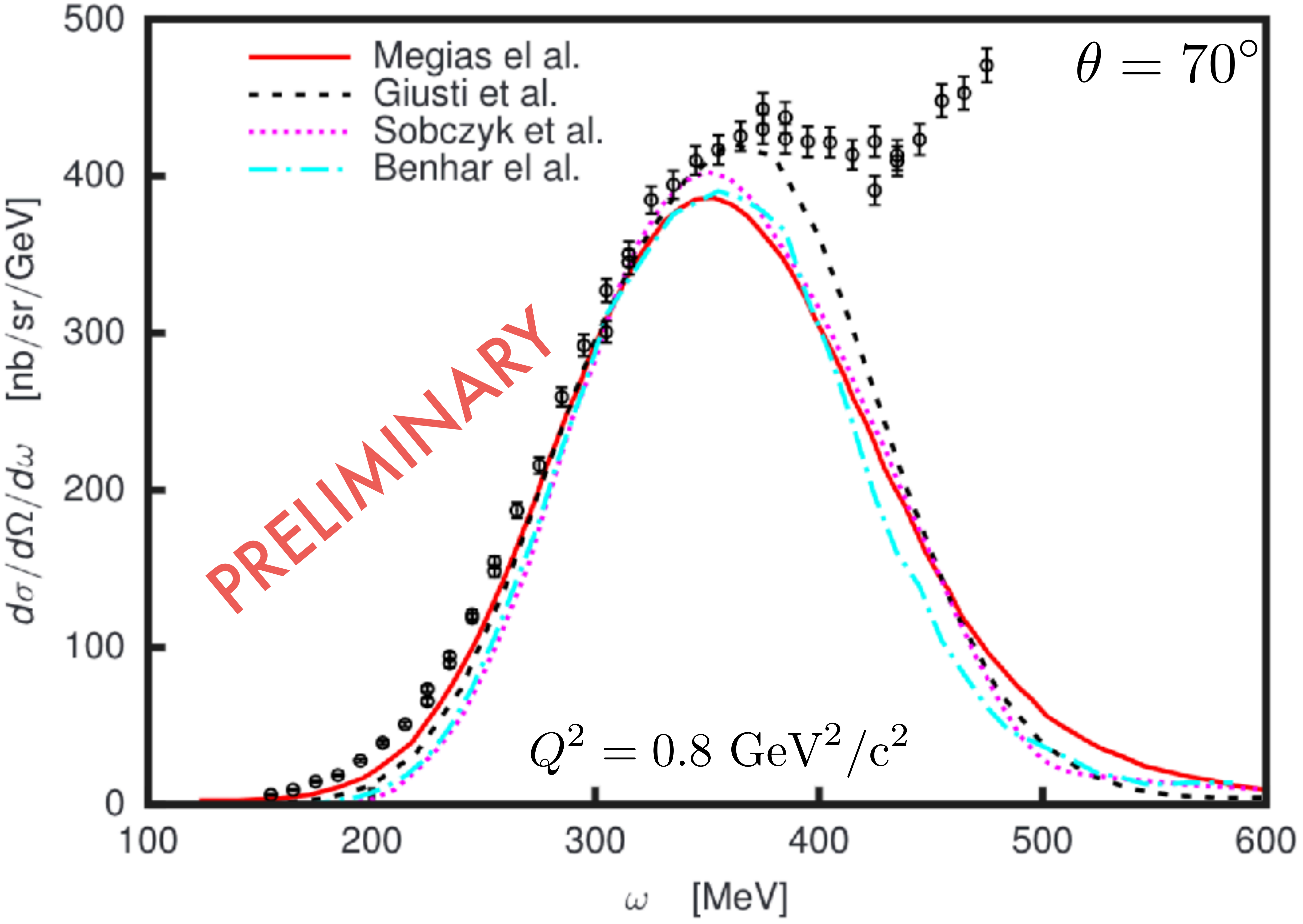
H. Dai et al, Phys. Rev. C 99, 054608 (2019)

Test ^{40}Ar MAMI (on-going!)



MAMI ^{12}C data



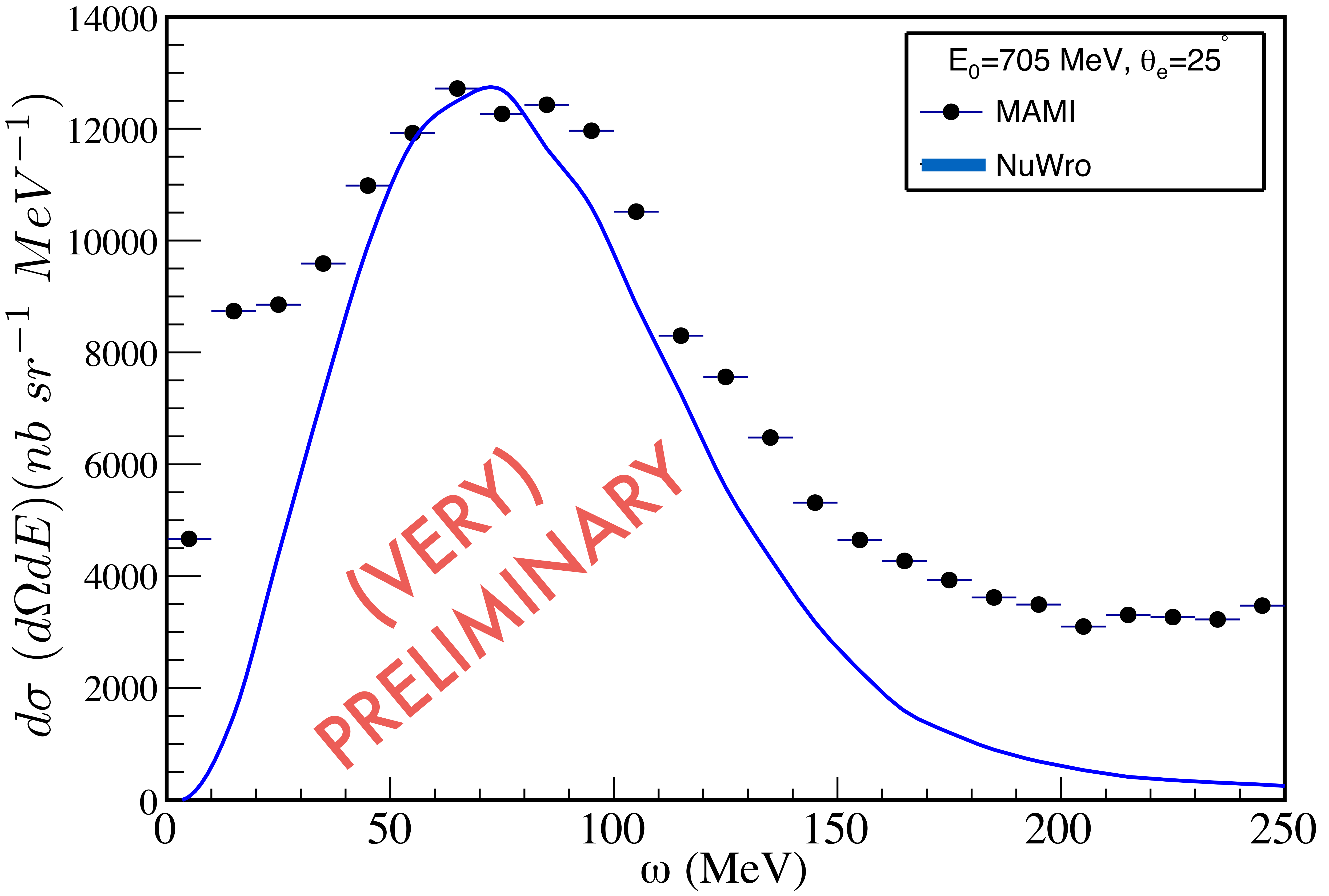


- Analysis: M. Mihovilovic (J.Stefan Inst.)
- GENIE (2.x tune) from A.Ankowski
- MEC / Resonance region more difficult to describe

- Quasi-Elastic region well described by theory
- Data - Megias et al. model

MAMI ^{40}Ar data

* Data taken 2 weeks ago
* First measurement on argon with jet target
    - Key milestone for MAGIX
    - Very low background
    - Gas jet: working towards liquid phase
* Luminosity to be calibrated
* Data at 20° to be analysed
* Plan: measure 32° ("Frascati kinematics")
* Move to higher angles if possible.
* Take data at lower beam energy (see next slide)
* ~6h measurement showed here.



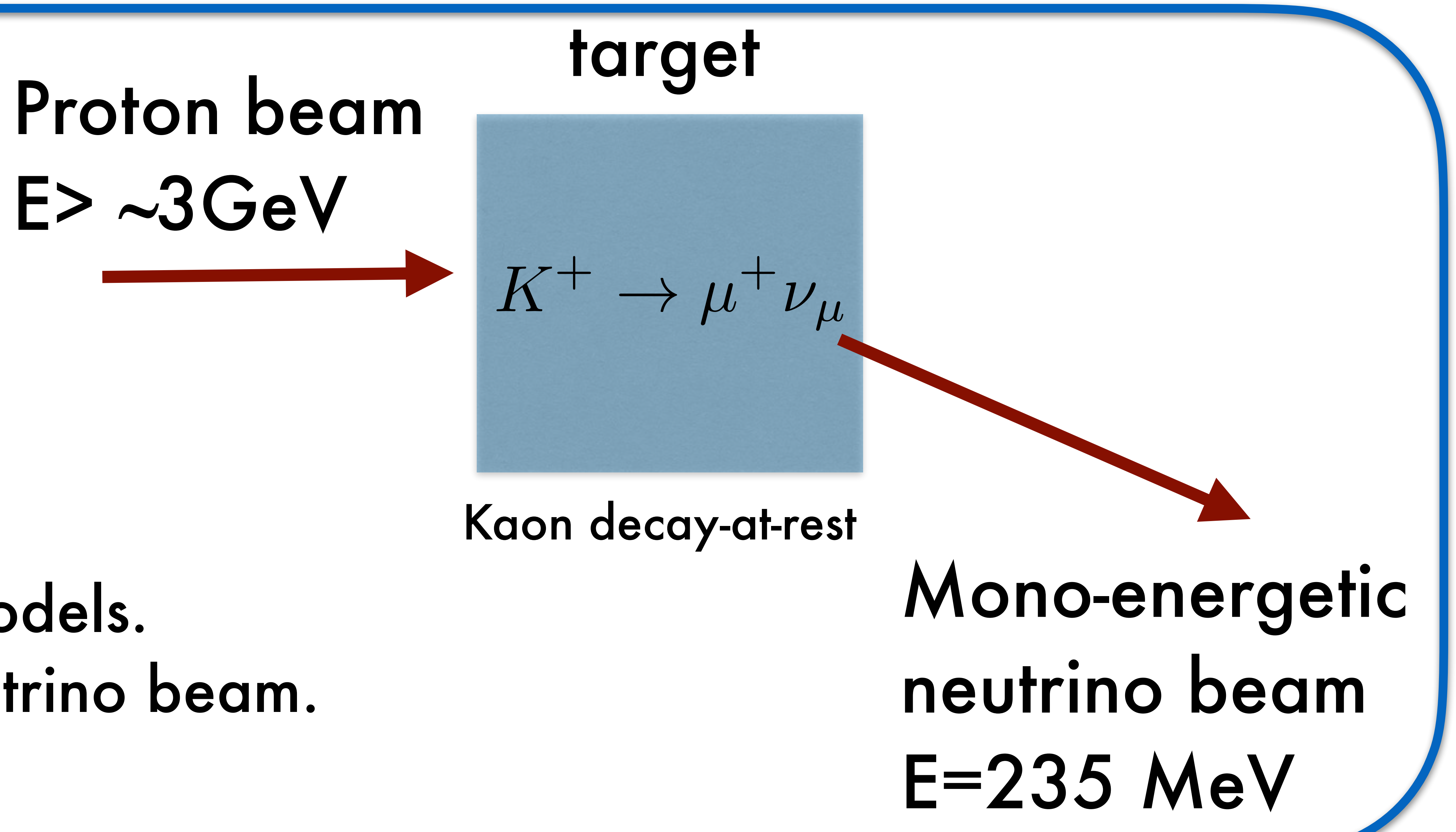
MAMI ^{40}Ar data (low energy)

Modeling quasielastic interactions of monoenergetic kaon decay-at-rest neutrinos

A. Nikolakopoulos,[1] V. Pandey,[2,*] J. Spitz,[3] and N. Jachowicz[1,†]

[1]*Department of Physics and Astronomy, Ghent University, Proeftuinstraat 86, B-9000 Gent, Belgium*
[2]*Department of Physics, University of Florida, Gainesville, FL 32611, USA*
[3]*University of Michigan, Ann Arbor, MI, 48109, USA*

https://arxiv.org/abs/2010.05794



Investigate argon at 235 MeV for testing low-energy nuclear models.
Kaon-DAR is an opportunity for obtaining a mono-energetic neutrino beam.

- MAMI can produce a 240 MeV beam.
- MESA: energy is too low.
- The jet-target at MAMI would be perfect (no walls, lower bkgs at low energy).
- <u>Test measurement planned for NEXT week</u>: likely last chance before MESA operation.
- For the future: high-pressure argon target? (more backgrounds, but feasible).

Summary and Future plans

Available beams:

up to 1.6 GeV at MAMI (10-100 uA current): optimal for T2K, or 1st maximum in DUNE, K-DAR physics, ...
100-150 MeV at MESA (~mA current): interesting for SN neutrinos, DM searches, COHERENT physics, ...

Detectors:

A1@MAMI: 3 magnetic spectrometers, neutron detector, pion spectrometer.
MAGIX@MESA: 2 magnetic spectrometers, silicon detectors.

Targets:

A1: solid-state (e.g. Be, C, Ca, ...), high-P (e.g. O, Ar, Xe), cryogenic (H, 2H, 3H, 3He, 4He), waterfall (H_2O)
MAGIX: gas-jet target (H, Ar, Xe, O??, ...). Possibility for solid-state (if beam-dump available)

Physics opportunities:

A1: inclusive and exclusive cross sections (exclusive: real target for neutrino physics and test for generators)
MAGIX: inclusive and exclusive cross sections (test for generators like MARLEY).
Complementarity with a JLab program at higher energies
Interesting for nuclear structure and reactions physics (modern ab-initio theory)

Exclusive channels capabilities:

N(e,e′p)N′, N(e,e′pp)N′. Neutron and pion production channels require more study but feasible in principle.